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TITLE: PRELIMINARY ECONOMIC ASSESSMENT OF RESIDENTIAL PASSIVE SOLAR COOLING POTENTIAL IN THE UNITED STATES

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PRELIMINARY ECONOMIC ASSESSMENT OF RESIDENTIAL PASSIVE SOLAR COOLING POTENTIAL IN THE UNITED STATES

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ABSTRACT

In many areas of the continental United States, residential cooling loads are equal to or greater than energy used for residential space heating. Offsetting part of the cooling load could yield considerable dollar savings to the consumer as well as total energy savings. The physical performances of three passive cooling designs are used to estimate the dollar value of first-year fuel savings (excluding heating benefits) and a maximum affordable design cost. The designs include natural ventilation, forced ventilation, and evaporative cooling concepts. Because economic performance is primarily governed by the level of electricity prices, dollars savings are greatest in regions that show both good physical performance of the cooling design and high electricity prices. Physical and economic performance summaries are presented in mapped form for 220 solar regions within the continental United States.

1. INTRODUCTION

The economics of passive space heating has been the topic of many research efforts in recent years. Different approaches have been used to evaluate the prospect for passive designs of all types. Hypothetical subdivisions, existing custom-built homes, private schools, office buildings, and warehouses are among the types of buildings that have been studied. This paper leaves the realm of passive space heating and moves into the area of passive cooling, one of several strategies of bioclimatic design. While most designers understand the importance of integrating prevailing climatic conditions into the design process, many lack the tools and resources to do so. Preliminary analysis of evaporative and radiative cooling effectiveness has been completed, although of limited geographic scope (1).

This and other work attest to the need for expanded research in the area of passive cooling. A preliminary physical performance analysis of three cooling concepts was completed by the Solar Energy Group (Q-11) at Los Alamos National Laboratory (2). The results of this analysis, in which only cooling performance was considered, were used to assign cooling load displacement values to each of 220 solar regions. These values were combined with region-specific electricity prices and general economic parameters in an economic analysis of first-year fuel savings and a maximum affordable design cost (total cost goal) for each design. Any benefits attributable to heating offsets were excluded. The economic analysis is described in more detail in Section 2.

The results of the economic analysis were used for two puposes: 1) to compare the economic potential of the three cooling concepts, and 2) to estimate the aggregate savings realized by substituting for standard refrigerative air conditioning use in new single-family homes. Benefits from use of smaller units--still needed for part of the cooling load--were not included. The aggregate savings calculation was based on new home start figures and estimated first-year fuel savings. High-impact regions were then identified, where the residential cooling loads displaced by a passive cooling design were of particularly high economic value. Conclusions, along with mapped results, are presented in Section 3.

2. METHODOLOGY

The physical performance results of the natural ventilation, forced ventilation, and evaporative cooling concepts do not represent an exhaustive study and are preliminary in nature. The single-family unit under consideration was a modern 1200 square-foot home (50' by 24'), with its long axis oriented east-west and the shorter one north-south. The house was assumed to have walls and roof with R-20 insulation, and an effective infiltration rate of one-half air change per hour. All windows were assumed to be double-glazed and represent 15% of the wall area. The resulting heating load of this relatively "tight" house was 7200 Btu/°F-day or 36 MMBtu annually for a 5000 degree day location. Regional estimates of the cooling load ranged from a high of 37 MMBtu to a low of 1.9 MMBtu depending upon climate conditions, principally cooling degree days (see Map 1).

For the physical design of the ventilation systems, it was assumed that 300 square-feet of south wall were replaced by a double-glazed, 9-inch thick water wall. The total heat capacity of the water wall was estimated to be 14 MBtu/°F, a state-of-the-art passive design. The double-glazing was insulated and approximately one foot away from the water wall surface. In the natural ventilation concept, it was assumed that outside air would circulate by stack effect up the channel between the glazing and water wall surfaces. The forced ventilation concept included a system of fans and ducts to bring outside air in at a rate of 3000 cfm. In both ventilation designs, auxiliary cooling was allowed to take over at a temperature of 78°F. Maps 2 and 3 portray displaced cooling load for the natural and forced ventilation concepts.

The physical performance of the evaporative cooling design was calculated in a two stage process. The direct stage of evaporative cooling was assumed to take place at an outside dry bulb temperature above 75°F and outside wet bulb temperature below 67°F. The indirect stage was assumed to go into effect at a wet bulb temperature above 67°F, at which point outside air would be evaporatively cooled to 80% of the difference between wet and dry bulb temperatures. This air would remove heat from room air at 80% effectiveness. There was no cooling when the temperature drop across the heat exchanger was less than 5°F. Forced air flow of 3000 cfm was used in both stages. The estimated residential cooling load displaced by the evaporative design is portrayed in Map 4.

The Solar Energy Group used isopleths on the original performance maps to show patterns of cooling load displacement (in MMBtu). These isopleth maps were interpreted to provide a performance measure (also in MMBtu) for each of the 220 regions. By comparing Maps 2, 3, and 4 it is clear that the natural ventilation design would hold little promise for major displacement of cooling loads and that forced ventilation and evaporative concepts show much more promise. The highest estimates of performance for the forced ventilation design were found for all southern areas of the United States and fairly high levels of cooling load displacement in more than half of the continental area. The pattern of forced ventilation performance was roughly latitudinal. The levels of cooling load displacement along the coasts were less than for interior locations of like latitudes, reflecting diminished cooling requirements under a marine influence.

The evaporative cooling concept displayed a much different pattern of physical performance. Areas of high cooling load displacement were confined to the arid Southwest, although fairly high performance was estimated for the intermountain and coastal West. Not surprisingly, dramatically reduced performance estimates were found in more humid regions of the country.

The two economic performance measures calculated in this analysis were first-year fuel savings and total cost goal. The calculation of first-year fuel savings was straight-forward--simply the product of the displaced energy (MMBtu's) and regional fuel cost ($/MMBtu). It was assumed in this calculation that refrigerative air conditioning (electric) would be installed in a new home and used to fully offset cooling loads if a passive cooling design were not installed. Fuel prices for electricity (in cents per kWh) are displayed in Map 5.

The estimated total cost goal is defined as the present value of the stream of dollar fuel savings one could expect for the life of the design (assumed here to be 30 years). The total cost goal is a measure of the maximum dollar value one could afford to pay for the design in question and still just break even. For example, if the actual cost were less than the total cost goal, the consumer would be better off. If the actual cost were exactly equal to the total cost goal, the consumer would be "indifferent," that is, there would be no clear economic motive for making such an investment. Such a case is equivalent to a net present value of zero. The total cost goal is especially useful in characterizing a system for which design costs are not available. This economic indicator is described in further detail elsewhere (3).

A series of general economic parameters were defined for calculating the total cost goal. They are contained in Table 1. The last element of this economic analysis involved estimating the first-year fuel savings for only those residences "expected" to install air conditioning equipment. This measure was determined by the product of 1982 projected regional single-family home starts, regional proportions of central air conditioner usage, and

TABLE I. ECONOMIC PARAMETER VALUES

Down Payment Rate	20%
Property Tax Rate	2% of Cost
Combined Federal, State, and Local Tax Bracket	35%
Annual Operating and Maintenance Rate	1% of Cost
Annual Inflation Rate	8%
Interest Rate (real)	8%
Discount Rate (real)	5%
Annual Electricity Price Escalation Rate (real)	4%
System Life	30 Years

the first-year dollar savings associated with each design. Each regional housing start figure (based on National Association of Home Builders estimates) was adjusted by an air conditioner usage estimate to eliminate residences not expected to install air conditioners.

Passive solar cooling designs are of greatest potential economic benefit when offsetting use of an installed central refrigerative air conditioning system. Regions with greater demand for air conditioning would be expected to have greater demand for passive cooling designs and realize greater potential savings. These adjusted first-year savings estimates reflect a measure of each region's potential for fuel and dollar savings. Savings for all regions were summed to provide an estimate of nationwide first-year fuel and dollar savings.

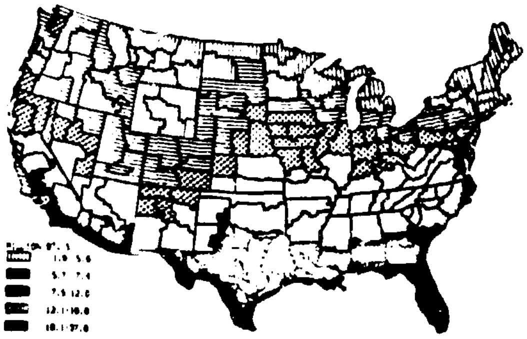
3. RESULTS AND CONCLUSIONS

Several important conclusions arise from the results of our analysis concerning the potential for residential passive cooling in the continental United States. First-year fuel savings, displayed in Maps 6 and 7 were far greater for forced ventilation and evaporative cooling than for the natural ventilation design. The values on Map 6 (for forced ventilation) are highest in the southern tier of regions. Regions in Florida, parts of Texas, and southern Arizona display especially high values for first-year savings, a finding that reflects both good design performance and fairly high fuel prices. Map 7 reveals that high dollar savings for the evaporative design are confined to the arid Southwest, reflecting the relatively small area of reasonable physical performance for this concept. Among the areas of greatest potential savings are southern Arizona and the El Paso, Texas, regions, where relatively high electricity prices and good design performance make the evaporative design more attractive.

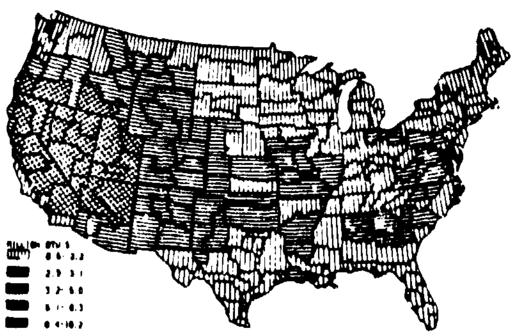
The total cost goal Maps 8 and 9 bear an expected, strong resemblance to Maps 6 and 7, for both first-year savings and total cost goal calculations are dominated by two variables--physical performance and fuel prices. The more interesting feature of these maps, however is not the pattern but the absolute level of total cost goal values. In order to pay for itself over 30 years, our results indicate that a passive solar cooling design could cost no more than $3100 under the more favorable conditions.

However, our calculations of savings and total cost goal have been confined to cooling performance only and could be somewhat misleading. Both evaporative cooling and forced ventilation have potential for residential space heating. If the heating performance were incorporated, the total cost goal would be in excess of $3100 and might, perhaps, be twice that amount. With heating and cooling performances considered, a water wall design costing as much as $20 per square foot might be cost effective. If the heating performance were substantially better than the cooling, the design cost could even rise substantially without threatening its cost effectiveness. Costs of these magnitude ($20/ft^2) compare favorably with current published costs for a water wall (4).

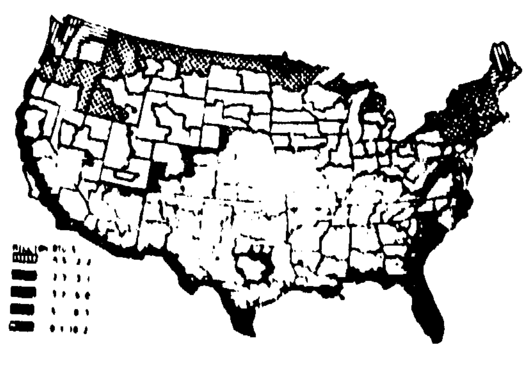
The last two maps (Maps 10 and 11) show regional aggregate first-year savings, explained earlier as the first-year dollar savings of one design multiplied by the number of new single-family home starts that use central refrigerative air conditioners. The Gulfcoast area along with southern Arizona and desert California have the greatest aggregate savings for the forced ventilation design. These savings reflect a high population growth, high cooling loads, and high fuel prices coupled with good physical performances. Southern Arizona and desert California have the highest aggregate savings for the evaporative concept, an effect of the limited applicability of the system.



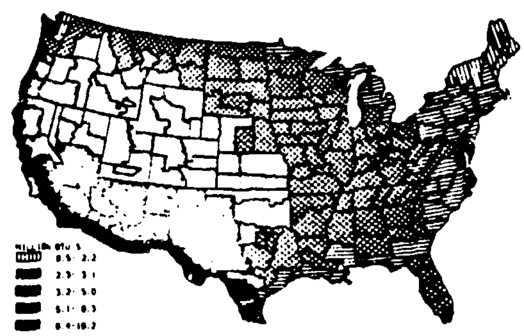
Map. 1. Total cooling load of base case residence.



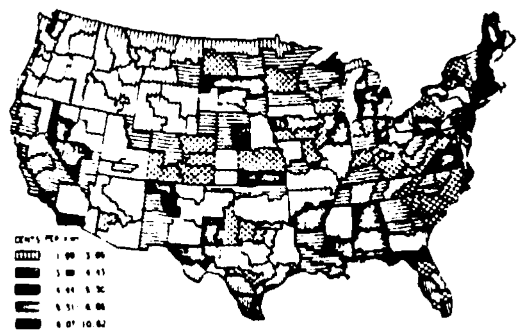
Map. 2. Residential cooling load displaced by natural ventilation.



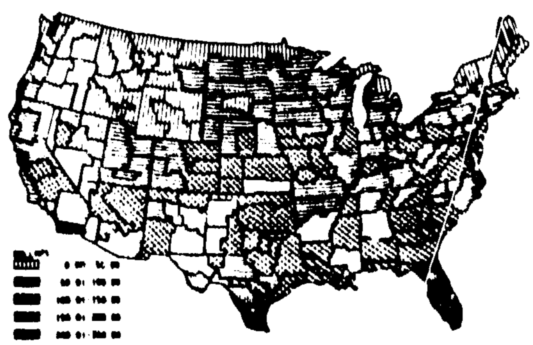
Map. 3. Residential cooling load displaced by forced ventilation.



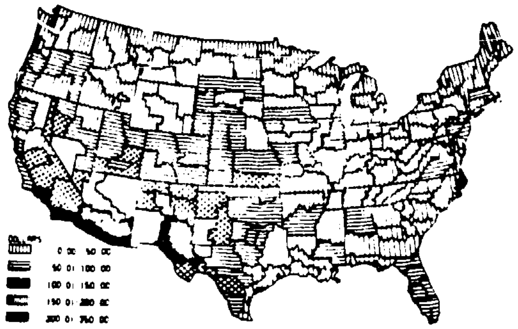
Map. 4. Residential cooling load displaced by evaporation.



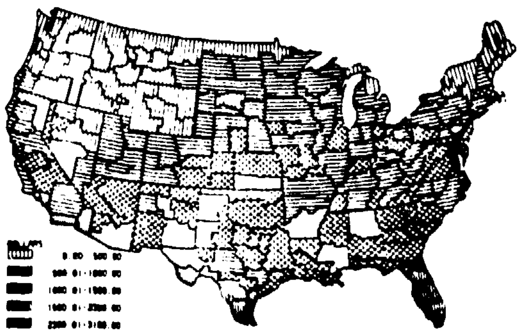
Map. 5. Electricity prices by region.



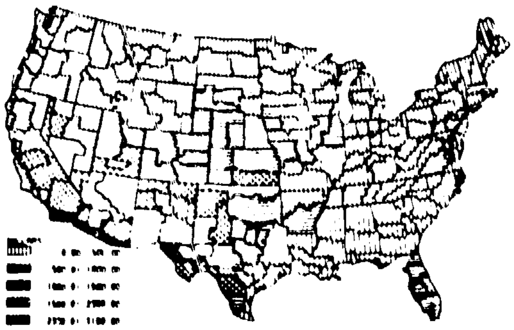
Map. 6. Dollar value of first-year fuel savings for forced ventilation.



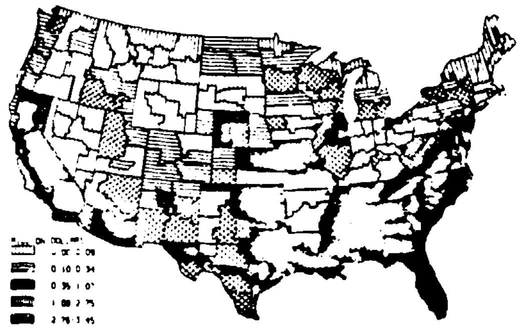
Map. 7. Dollar value of first-year fuel savings for evaporation.



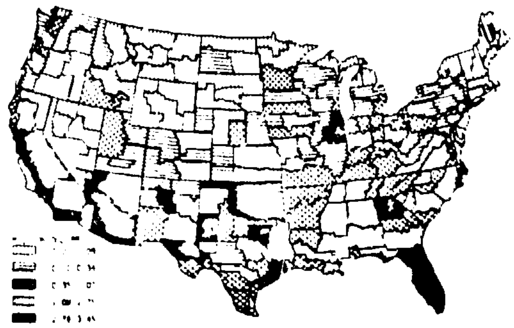
Map. 8. orced ventilation total cost goal.



Map. 9. Evaporation total cost goal.



Map. 10. Aggregate first-year savings for forced ventilation.



Map. 11. Aggregate first-year savings for evaporation.

Aggregate first-year savings, summed over all regions, was estimated to be $56 million for forced ventilation and $33 million for evaporative cooling. These figures represent nationwide fuel savings for one year from displacement of cooling loads. However, much greater savings would be realized if the best concept were used for each region. Furthermore, a higher figure would result if heating fuel savings of these passive designs were incorporated into the calculation. Work in this area will be completed in the near future.

4. ACKNOWLEDGEMENT

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